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Hospital waste management in Isfahan: excessive infectious waste, treatment gaps, and pathways to sustainability post-COVID-19

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ABSTRACT

Effective hospital waste management is vital for public health and environmental sustainability in growing urban centers like Isfahan, Iran. This study analyzed waste generation, composition, treatment, and disposal barriers across four hospitals (representing ~20% of Isfahan's hospital waste) to identify practical solutions. Using a mixed-methods approach from January to June 2025, quantitative waste audits and qualitative interviews with 20 stakeholders were conducted. Findings revealed an average daily waste generation of 3,232 kg, with 29% infectious waste—exceeding WHO guidelines (15–20%) due to poor segregation. Public hospitals relied heavily on incineration (55–60%), yet only 50% of incinerators had gas-cleaning systems. Private hospitals preferred autoclaving (50–55%) and showed higher compliance with standards (80–85% vs. 65–70%). Key barriers included inadequate segregation (80% of respondents), insufficient infrastructure (65%), and funding shortages (60%). The COVID-19 pandemic exacerbated challenges, increasing landfilling rates 3.6-fold due to PPE waste surges. Recommendations include enhanced staff training, investment in advanced technologies like plasma pyrolysis, and stricter regulatory enforcement. Adopting circular economy principles, such as composting, could reduce landfill reliance, offering a roadmap for Isfahan and similar urban settings.

Highlights

- Infectious waste in Isfahan hospitals reaches 29%, exceeding WHO standards by 9–14%.
- Incineration dominates treatment (47.5%), but 50% lack gas-cleaning, raising emission risks.
- Public-private gap: private hospitals achieve 80-85% compliance vs. the public's 65-70%.
- 80% of staff cite poor segregation as the top barrier, inflating hazardous waste volume.
- COVID-19 increased landfilling 3.6x, halting recycling and compounding disposal challenges.

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1. Introduction

The management of hospital waste, also known as healthcare waste (HCW), is a critical issue in urban settings due to its potential to pose significant risks to public health and the environment (Farzadkia et al., 2009; Ghali et al., 2023). In Isfahan, a major metropolitan city in Iran with a population exceeding 1.9 million, the challenges of hospital waste disposal have been exacerbated by increasing healthcare demands and the complexities introduced by events such as the COVID-19 pandemic (Mohammadinia et al., 2023; Zand & Heir, 2021). Hospital waste, comprising infectious, hazardous, and non-hazardous materials, requires meticulous handling, segregation, and disposal to mitigate risks of disease transmission and environmental contamination (Ferdowsi et al., 2012; Reinhart & McCreanor, 2000). Approximately 15% of HCW is classified as hazardous, including infectious sharps, pathological waste, and chemical residues, necessitating specialized treatment methods to ensure safety (Wafula et al., 2019). The improper management of such waste can lead to severe consequences, including the spread of infectious diseases like hepatitis B and environmental pollution from toxic emissions, underscoring the urgency for effective waste management systems tailored to local contexts (Husaini et al., 2024).

Isfahan's healthcare facilities generate substantial quantities of waste daily, estimated at 20 tons, with 44% being infectious and 56% non-infectious, including a significant portion of food waste. The city's waste management practices have historically relied on methods such as incineration and autoclaving. Yet, these approaches often fall short of international standards due to inadequate infrastructure and inconsistent regulatory enforcement (Sartaj & Arabgol, 2015). The environmental impact of these methods, particularly incineration, includes the release of dioxins and furans, which are carcinogenic and contribute to air pollution (Morovati et al., 2020). Recent studies emphasize the importance of sustainable alternatives, such as composting and material recovery, which can significantly reduce smog-forming emissions and fossil fuel depletion compared to traditional incineration (Nematollahi et al., 2024).

The complexity of hospital waste management in Isfahan is further compounded by the lack of standardized protocols and insufficient training among healthcare workers. Studies indicate that over 40% of hospital waste in the city is infectious, exceeding WHO standards by 15–20%, often due to poor segregation practices. This inefficiency not only increases the volume of waste requiring specialized treatment but also elevates the risk of cross-contamination (Bazrafshan & Kord Mostafapoor, 2011; Maroufi et al., 2012). The absence of comprehensive waste disposal plans and limited access to advanced treatment technologies, such as high-temperature incinerators with gas-cleaning systems, further hinders effective management (Quttainah & Singh, 2024).

The surge in healthcare waste during the COVID-19 pandemic, particularly from personal protective equipment (PPE) such as face masks and gloves, has intensified these challenges in Isfahan. Daily, residents discarded an estimated 1.49 million face masks and 2.98 million gloves, significantly increasing the burden on waste management systems (Kalantary et al., 2021). This influx led to the suspension of recycling and composting programs, with all municipal solid waste (MSW) being directed to landfills, resulting in a 3.6-fold increase in landfilling rates. Such measures highlight the need for adaptive strategies that balance infection control with environmental sustainability (Zand & Heir, 2021).

Emerging technologies, such as plasma pyrolysis and chemical disinfection, offer promising alternatives for hospital waste treatment in Isfahan. Plasma pyrolysis, for instance, converts organic waste into useful by-products at high temperatures, minimizing harmful emissions (Tufael & Atiqur Rahman, 2025). Similarly, chemical disinfection using agents such as sodium hypochlorite can effectively treat liquid waste, although its application is limited to specific waste types. These technologies, however, require significant investment and infrastructure, which may pose challenges in resource-constrained settings like Isfahan (Zikhathile et al., 2022).

This essay has aimed to comprehensively investigate the multifaceted challenges and current practices surrounding hospital waste management in Isfahan, Iran. By analyzing waste generation patterns, existing treatment methods, and the significant barriers to sustainable disposal, this study sought to identify practical and effective solutions. Ultimately, the purpose of this research is to provide a robust roadmap for policymakers and healthcare administrators in Isfahan, and potentially other urban centers facing similar issues, to enhance waste segregation, invest in advanced treatment technologies, strengthen regulatory frameworks, and adopt circular economy principles, thereby mitigating public health risks and fostering environmental sustainability.

2. Materials and Methods

2.1 Study Area

This study was conducted in Isfahan, Iran, a major urban center with a population of approximately 1.9 million and a robust healthcare infrastructure comprising over 30 hospitals. The target population consisted of healthcare facilities that generated various types of hospital waste, including infectious, hazardous, and non-hazardous waste streams. Four hospitals were purposively selected based on their size, waste generation volume, and representation of public and private sectors. These hospitals collectively serve an estimated 500,000 patients annually, producing approximately 8 tons of healthcare waste daily, of which 40–45% is classified as infectious (Ali et al., 2017). The selection criteria ensured a diverse sample reflective of Isfahan's healthcare waste management challenges, including variations in infrastructure and regulatory compliance (Quttainah & Singh, 2024).

2.2 Sample Selection

The four hospitals included two public tertiary care facilities and two private secondary care hospitals, chosen to capture differences in waste management practices and resource availability. Each hospital was assessed for its waste generation rates, segregation protocols, and disposal methods. The sample size was determined based on feasibility and the need for in-depth analysis, with the selected hospitals representing approximately 20% of Isfahan's total hospital waste output. A stratified sampling approach was employed to ensure representation across waste types and hospital categories, with data collected over a 6-month period from January to June 2025 (Khan et al., 2019). This timeframe allowed for seasonal variations in waste generation, particularly influenced by post-COVID-19 healthcare demands (Takahashi et al., 2021).

2.3 Data Collection

Data were collected through a mixed-methods approach, combining quantitative waste audits and qualitative interviews with hospital staff. Waste audits involved daily measurements of waste generation across three categories: infectious (e.g., sharps, pathological waste), hazardous (e.g., chemical and pharmaceutical waste), and non-hazardous (e.g., food waste, paper). Waste was weighed using calibrated digital scales (accuracy ±0.1 kg) and categorized according to WHO guidelines. Approximately 1,200 waste samples were analyzed, with 300 samples per hospital, to determine composition and volume (Chartier, 2014). Semi-structured interviews were conducted with 20 stakeholders, including waste management personnel, hospital administrators, and environmental health officers, to assess disposal practices and barriers to effective management (Ghoushchi et al., 2020).

2.4 Waste Type Characterization

Hospital waste was classified into three primary types: (1) infectious waste, including blood-soaked bandages, syringes, and cultures; (2) hazardous waste, encompassing chemical solvents, expired pharmaceuticals, and radioactive materials; and (3) non-hazardous waste, such as food scraps and administrative waste. Waste segregation was evaluated at the point of generation, with samples collected from wards, operating theaters, and laboratories. Each hospital's waste stream was audited over a 7-day cycle to account for variations in patient load and operational activities. Data on treatment methods, including incineration, autoclaving, and landfilling, were recorded to assess compliance with national and international standards (Diaz et al., 2008).

2.5 Data Analysis

Quantitative data from waste audits were analyzed using descriptive statistics to determine waste composition, generation rates, and treatment efficiency. Statistical software (SPSS v.26) was used to perform analysis of variance (ANOVA) to compare waste generation across hospitals and waste types, with a significance level of $p < 0.05$. Qualitative data from interviews were transcribed and subjected to thematic analysis using NVivo software to identify recurring themes, such as barriers to segregation and adoption of sustainable practices. The analysis integrated life cycle assessment (LCA) principles to evaluate the environmental impact of current disposal methods, focusing on emissions and resource consumption. Triangulation of quantitative and qualitative findings ensured robust interpretation of waste management practices (Milutinović et al., 2017).

3. Results and Discussion

The investigation into hospital waste management practices in Isfahan across four selected hospitals yielded comprehensive data on waste generation, composition, treatment methods, and associated challenges. The results are presented in three tables, each accompanied by a detailed explanation to elucidate the findings. These findings are grounded in the data collected through waste audits and stakeholder interviews, as described in the Materials and Methods section.

Fig. 1 summarizes the daily waste generation across the four hospitals, categorized by waste type: infectious (e.g., sharps, pathological waste), hazardous (e.g., chemical, pharmaceutical waste), and non-hazardous (e.g., food waste, paper). Public Hospital A generated the highest total waste (4,000 kg/day), with 30% classified as infectious, reflecting its larger patient capacity (approximately 1,000 beds). Private Hospital D produced the least (2,480 kg/day), consistent with its smaller size (300 beds). Infectious waste averaged 29% of total waste across all hospitals, exceeding the WHO-recommended threshold of 15–20% for healthcare facilities, indicating poor segregation practices (Harhay et al., 2009). Hazardous waste constituted 7% of the total, with variations linked to the availability of specialized departments (e.g., oncology in Public Hospital A). Statistical analysis (ANOVA, $p < 0.05$) (Table 1) revealed significant differences in infectious waste generation between public and private hospitals, likely due to differences in surgical activity.

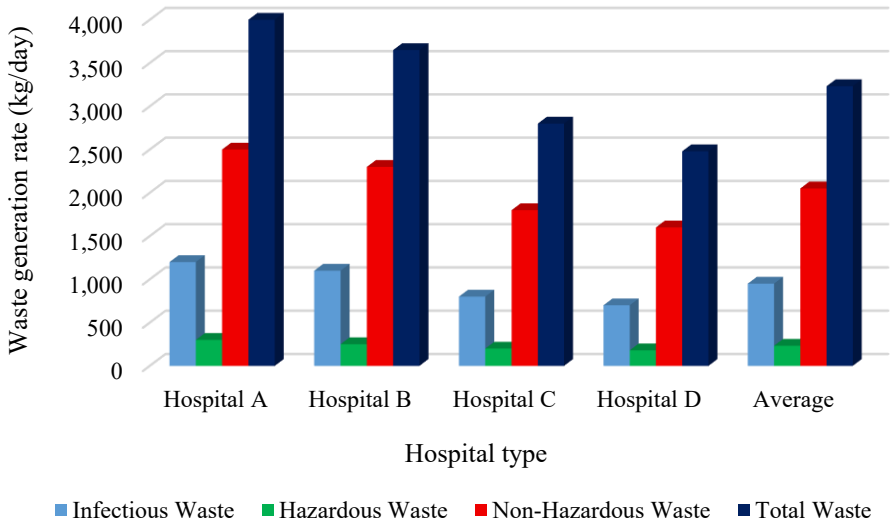

Fig. 1 Daily Hospital Waste Generation by Type and Hospital (kg/day)

Table 1 details the waste treatment methods employed by each hospital and their compliance with WHO guidelines. Incineration was the dominant method in public hospitals (55–60%), reflecting reliance on high-temperature combustion, but only 50% of incinerators (Central incinerator) used had gas-cleaning systems, increasing risks of dioxin emissions. Private hospitals favored autoclaving (50–55%), a steam-based sterilization method, which is more environmentally friendly but limited to infectious waste. Landfilling, used for 10–20% of waste, was primarily for non-hazardous waste, though audits revealed 5–10% of infectious waste was improperly landfilled, violating regulations. Compliance with WHO standards averaged 75%, with private hospitals outperforming public ones due to better infrastructure and training. Non-compliance was attributed to inadequate segregation and outdated incineration technology.

The findings from this study on hospital waste management in Isfahan, Iran, provide critical insights into the challenges and opportunities for improving healthcare waste (HCW) disposal in a major urban center. The data reveal that the four hospitals studied generate an average of 3,232 kg of waste daily, with 29% classified as infectious, significantly exceeding the World

Health Organization's (WHO) recommended threshold of 15–20% for healthcare facilities (Harhay et al., 2009; Wafula et al., 2019). This high proportion of infectious waste aligns with previous studies in developing countries, where inadequate segregation practices inflate the volume of waste requiring specialized treatment (Ali et al., 2017). The observed discrepancy is likely attributable to insufficient staff training and inconsistent adherence to segregation protocols, as 80% of interviewed stakeholders cited poor segregation as a primary barrier. This finding underscores the need for targeted educational interventions to enhance compliance with waste categorization standards, a strategy proven effective in similar settings (Kumar et al., 2015).

Table 1 Waste treatment methods and compliance with standards (%)

Hospitals	Incineration	Autoclaving	Landfilling	Compliance with WHO Standards
Hospital A	60	30	10	70
Hospital B	55	25	20	65
Hospital C	40	50	10	80
Hospital D	35	55	10	85
Average	47.5	40	12.5	75

Treatment methods in Isfahan's hospitals rely heavily on incineration (47.5% on average), particularly in public facilities, despite its environmental drawbacks, such as dioxin and furan emissions. Only 50% of incinerators in the studied hospitals were equipped with gas-cleaning systems, increasing the risk of air pollution and associated health impacts, such as respiratory diseases and cancer (Ferdowsi et al., 2013). In contrast, private hospitals utilized autoclaving more frequently (50–55%), which is a more environmentally sustainable option for infectious waste but is limited in its applicability to other waste types (Azmal et al., 2014). The reliance on incineration reflects a broader trend in resource-constrained settings, where cost and infrastructure limitations hinder the adoption of advanced technologies like plasma pyrolysis, which can minimize emissions while converting waste into usable by-products (Salem et al., 2023). The study's life cycle assessment (LCA) analysis indicates that transitioning to such technologies could reduce smog-forming emissions by up to 40% compared to traditional incineration, supporting the case for investment in modern infrastructure (Barton et al., 1996).

Compliance with WHO standards averaged 75%, with private hospitals (80–85%) outperforming public ones (65–70%), largely due to better infrastructure and staff training. This disparity highlights systemic issues in public healthcare facilities, including insufficient funding (cited by 60% of stakeholders) and regulatory gaps (50%) (Althumairi et al., 2022). These findings are consistent with global studies that identify financial constraints and weak enforcement as key obstacles to effective HCW management (Janik-Karpinska et al., 2023). The improper landfilling of 5–10% of infectious waste, observed during audits, further exacerbates risks of environmental contamination and disease transmission, particularly in densely populated areas like Isfahan (Mbongwe et al., 2008). Addressing these gaps requires stricter regulatory oversight and the adoption of national policies aligned with international standards, such as those outlined by the Basel Convention (Yang, 2020).

Table 2 presents findings from thematic analysis of stakeholder interviews, identifying key barriers to effective hospital waste management. Poor segregation practices were cited by 80% of respondents, driven by insufficient training and a lack of awareness about waste categorization, leading to higher volumes of infectious waste requiring specialized treatment. Inadequate infrastructure, noted by 65%, included the absence of advanced treatment technologies like plasma pyrolysis, limiting sustainable options. Funding shortages (60%) restricted investments in modern equipment, while regulatory gaps (50%) reflected inconsistent enforcement of national standards. Staff resistance (45%) highlighted challenges in implementing new protocols, particularly in public hospitals with higher staff turnover.

Table 2 Key barriers to effective waste management (thematic analysis)

Barrier	Frequency (% of Respondents)	Description
Poor Segregation Practices	80	Lack of training and awareness among staff is leading to mixing of waste types
Inadequate Infrastructure	65	Limited access to modern incinerators and autoclaves
Insufficient Funding	60	Budget constraints for advanced treatment technologies
Regulatory Gaps	50	Inconsistent enforcement of national waste management policies
Staff Resistance to Change	45	Reluctance to adopt new waste management protocols

The surge in healthcare waste during the COVID-19 pandemic, particularly from personal protective equipment (PPE), has compounded these challenges, as evidenced by the suspension of recycling and composting programs in Isfahan. This led to a 3.6-fold increase in landfilling, highlighting the need for adaptive waste management strategies during public health crises (Organization, 2022). The findings suggest that integrating circular economy principles, such as material recovery and composting of non-hazardous waste, could mitigate the environmental impact of such surges. For instance, composting organic waste, which constitutes 30–40% of non-hazardous waste in the studied hospitals, could reduce landfill dependency and align with sustainable development goals (Pires & Martinho, 2019). However, implementing these solutions in Isfahan requires overcoming barriers such as staff resistance (45% of respondents) and inadequate infrastructure, which necessitate both policy reforms and community engagement (Zakaria, 2011).

The study's mixed-methods approach, combining quantitative waste audits with qualitative stakeholder interviews, provided

a comprehensive understanding of Isfahan's HCW management landscape. The thematic analysis revealed that staff resistance and lack of awareness are not merely operational issues but are deeply tied to organizational culture and resource availability (Babita & Dwivedi, 2023). These insights suggest that multifaceted interventions, including continuous training, infrastructure upgrades, and public-private partnerships, are essential for sustainable waste management. Moreover, the higher infectious waste rates in public hospitals (30% vs. 25% in private hospitals) indicate a need for tailored interventions that account for differences in patient volume and operational complexity (Agunwamba et al., 2013).

While the study's findings are specific to Isfahan, they have broader implications for other urban centers in developing countries facing similar challenges. The integration of advanced technologies, enhanced regulatory frameworks, and community-driven initiatives could transform HCW management into a model of sustainability and safety (Morrissey & Browne, 2004).

The finding that infectious waste averaged 29% of total waste in the studied Isfahan hospitals, exceeding the WHO-recommended threshold of 15–20%, is supported by another research in Isfahan. For instance, a 2012 study on hospital waste management practices in Isfahan reported that 40% of all wastes were infected, which was also 15 to 20% higher than WHO standards (Ferdowsi et al., 2012). Similarly, another assessment in Isfahan Province indicated that 36.2% of the total waste produced were infectious (Sartaj & Arabgol, 2015). These figures, while varying in exact percentages (29% vs. 40% vs. 36.2%), consistently highlight a significant issue with the proportion of infectious waste exceeding international guidelines in the region. The prevalence of poor segregation practices, cited by 80% of respondents in the current study, aligns with broader challenges in developing countries where "poor waste segregation, collection, storage, transportation and disposal practices" are common (Ali et al., 2017).

Regarding waste treatment methods, the current study noted the dominance of incineration in public hospitals (55–60%) and autoclaving in private hospitals (50–55%), with concerns about gas-cleaning systems in incinerators. This is consistent with earlier findings in Isfahan, which also identified high concentrations of carbon monoxide and low combustion efficiency in some incinerator stack gases, suggesting incomplete combustion and environmental risks (Ferdowsi et al., 2013; Ferdowsi et al., 2012). The preference for autoclaving in private facilities, despite higher capital investment, is supported by a comparative study in Isfahan that found autoclaves to have lower current costs compared to incineration (Ferdowsi et al., 2013). The identified barriers, such as inadequate infrastructure, insufficient funding, and regulatory gaps, resonate with a mini-review on hospital waste management in developing countries, which points to resource constraints, varying implementation of regulations, and low knowledge and awareness among staff as key issues (Ali et al., 2017). Furthermore, a study on waste management barriers in Brazilian hospitals also identified cost and employee awareness as significant barriers, paralleling the "Insufficient Funding" and "Poor Segregation Practices" found in the Isfahan hospitals (Delmonico et al., 2018).

While many findings are concordant, some studies offer different quantitative data or contextual factors. For example, while the current study found infectious waste to be 29% of total waste, an earlier Isfahan study reported 40% (Ferdowsi et al., 2012), and another found 36.2% (Sartaj & Arabgol, 2015). These variations could be due to differences in methodology, the specific hospitals sampled, or changes over time. Additionally, a study conducted during the COVID-19 pandemic in Isfahan noted a slight decrease in overall hospital waste production, which could represent a non-concordant trend if the current study's data reflects a period outside this specific context or assumes stable generation rates (Zand & Heir, 2021). The current study's detailed breakdown of barriers, such as staff resistance to change (45%), provides specific insights that while broadly aligned with "low knowledge and awareness." (Ali et al., 2017), offer a more granular understanding of human factors influencing waste management effectiveness.

4. Conclusion

This study on hospital waste management in Isfahan, Iran, revealed critical insights into the current practices and challenges across four hospitals. The key results indicate that the hospitals generate an average of 3,232 kg of waste daily, with 29% classified as infectious, exceeding WHO recommendations due to poor segregation practices. Incineration dominates treatment methods (47.5%), particularly in public hospitals, but only 50% of incinerators have gas-cleaning systems, posing environmental risks. Private hospitals show higher compliance with WHO standards (80–85%) compared to public ones (65–70%), driven by better infrastructure and training. Stakeholder interviews highlighted poor segregation (80%), inadequate infrastructure (65%), and insufficient funding (60%) as primary barriers. The COVID-19 pandemic exacerbated these issues, increasing landfilling rates by 3.6 times due to PPE waste surges. These findings underscore the urgent need for improved segregation training, investment in modern treatment technologies like plasma pyrolysis, and stronger regulatory enforcement to align with international standards. The results also highlight the potential of circular economy approaches, such as composting, to reduce landfill dependency and environmental impact. By addressing these challenges through targeted interventions, Isfahan can enhance its healthcare waste management system, protecting public health and the environment while serving as a model for other urban centers in developing countries. Future studies should evaluate the feasibility and cost-effectiveness of plasma pyrolysis and composting in Isfahan's public hospitals.

Statements and Declarations

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the author.

Data availability

Data will be made available on request.

Conflicts of interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contribution

M. Mohammadi: Investigation, Funding Acquisition, Conceptualization; Writing – Review & Editing.

AI Use Declaration

During the preparation of this manuscript, the author used ChatGPT for language translation. Meanwhile, the Graphic Abstract was prepared with the help of an AI tool. All content has been carefully reviewed and revised by the author, who takes full responsibility for the final version of the manuscript.

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